Invited Further Response to the 'Water Statement of Common Ground'

By:	Dr Michael Rivett FGS (Director, GroundH_2O Plus Ltd)
Date:	27 November, 2021
Use:	Appeal **APP/M1900/W/21/3278097** (Nov. 2021) on rejection of proposed quarrying activity, Hatfield Aerodrome
Witness called by:	Ellenbrook Area Residents Association (EARA) and Smallford Residents Association (SRA)

Context

Please find below my further response to the Water Statement of Common Ground (SoCG) following the invitation extended by the Planning Inspector at the Appeal on 17th November 2021 due to the lateness of provision of the SoCG. These comments extend from my previous response documents that should also be consulted:

- ID-15 - Dr Rivett Outline response to updated SoCG and Jenny Lightfoot PoE
- EARA-SRA-MR-01 Dr M Rivett - Proof of Evidence.pdf

I do take the liberty to include and iterate some of the previous figures and provide associated text that may help clarify my viewpoints. Some update is made in response to the Appeal discussions where my interpretations differed to SoCG signatories.

Comments

[1] – Sporadic bromate detections on the quarry Site

EARA have long held concerns that sporadic bromate detections close to, or above the '2 µg/L plume threshold' that have occurred across the quarry 'Site' monitoring in both the LMH and Chalk have not been adequately explained or considered in the Site decision making process. These still seem unexplained following the discussions of 17th November:

- The EA (Environment Agency) response on 'averaging' bromate concentrations across time (years of data) appeared to echo our concern and appear not to fully engage with explaining the sporadic Site bromate detections, but rather 'average them away'. Noting SLR's indicated response that they did not 'average concentration data' is acceptable and expected practice – SRK appeared to be confirming not averaging concentration data on a single sampling event date. I would expect that would be the

case and the comment was not that relevant to our concern with the EA averaging statement.

- SLR pointed to 'lab errors' as being a possible explanation. Whilst accepting lab errors (and I might add field sampling errors – eg mixed up sample labels) may occur; however, given the significance of detections, if lab errors had been suspected this should have triggered follow-up sampling or re-analysis at the time to establish as far as possible data correctness. The presumption is that these are not lab errors.
- AW (Affinity Water) pointed to possible influence of seasonal conditions and observations of higher bromate concentrations at low water tables that could explain occasional event observations - has the data been examined to test this reasonable hypothesis?
- The EA later pointed to a lack of 'footprint' signature from matrix diffusion of a plume previously on Site, but it could be argued that the low concentrations occasionally observed are in fact weak, transient evidence of that footprint (but possibly not, see further below).

Overall, no consistent explanation is given as to why the bromate plume is sporadically found on Site. An obvious concern is that the discrete parts of the bromate plume could have slipped through the monitoring network, e.g. through the half-a-mile gap in the Site Northeast boundary LMH monitoring network, especially within the more permeable discrete gravel channels that exist within the LMH. Bromate concentrations in discrete gravel channels could be diluted with recharge water and perhaps could account for the transient detections.

[2] – Uncertainties in conceptual model understanding of Site - Bromate plume interaction

Following discussions at the Appeal, I still hold some differences in opinion on conceptual model controls on the bromate plume interaction with the Site. Respecting other views, I do largely stand by my data interpretation offered in ID-15 as very plausible and reiterate it here to highlight some concerns and support some of my later statements.

Examining boreholes in the main plume core area north of Site (Fig. 1):

- **BH305**, of all the boreholes examined, shows greatest similarity of bromate in the LMH and chalk suggestive of hydraulic continuity between them in the plume core. Bromate concentrations there would have had long timeframes to achieve stable interactions which will decline towards the plume margins. The LMH exhibits higher bromate concentration than the chalk that possibly relates to greater source terms of bromate still residing at shallower horizons nearer the bromate source.
- **BH105** likewise shows generally higher (to around double) concentrations in the LMH compared to the chalk underlining the importance of LMH to storage of bromate plume mass. In contrast to BH305, temporal trends are notably different in LMH and chalk, in fact opposing at times. This does not suggest much continuity between the chalk and LMH here and different controlling processes.

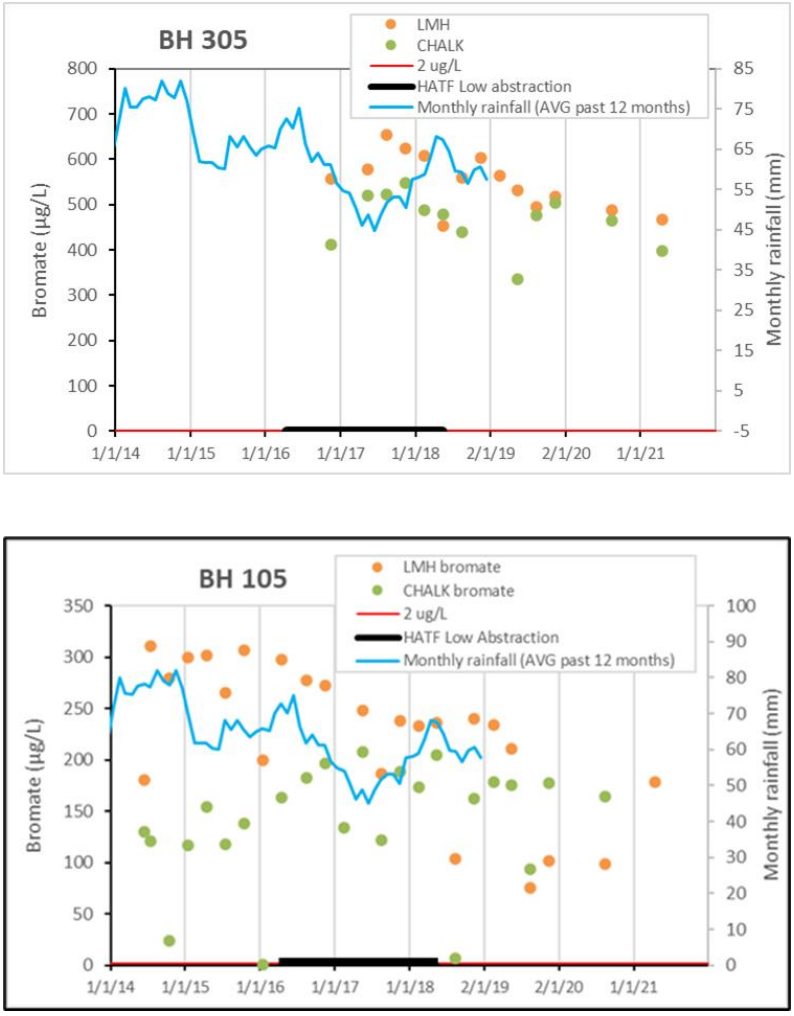


Fig. 1. Bromate concentrations at monitoring points BH308 and BH105 around the plume core remote from Site.

Examining the boreholes located increasingly closer to the Site (Figure 2):

- **BH108**. LMH bromate appears anomalously low compared to the chalk relative to other boreholes. LMH bromate does not fit spatial concentration trends. For instance BH201L closer to the Site has higher concentration illustrating the spatial heterogeneity (variability) of the plume and raises issues in reliable contouring the plume edge with limited data. Trends are notably different in the LMH and chalk and do not suggest local hydraulic continuity. Chalk shows a declining trend overall that is not shown by the LMH; in recent times bromate is increasing as chalk declines. I would maintain that the LMH bromate concentrations displaying a consistently low bromate during the 2016-18 Bishop's Rise low abstraction period may be influenced by changes in that abstraction rate (recognising too other influences may co-occur). Bromate appears to gradually decline during abstraction low followed by a gradual increase over 2 to 3 years back to pre-low-abstraction period concentrations as pumping increased. This may be very reasonably interpreted as a SLOW lateral drift of the plume transversely across 108 in the LMH back and forth, away from and then towards the quarry Site in response to decreased abstraction and northward plume drift and

increased abstraction causing southward drift . This LMH behaviour appears isolated from the chalk.

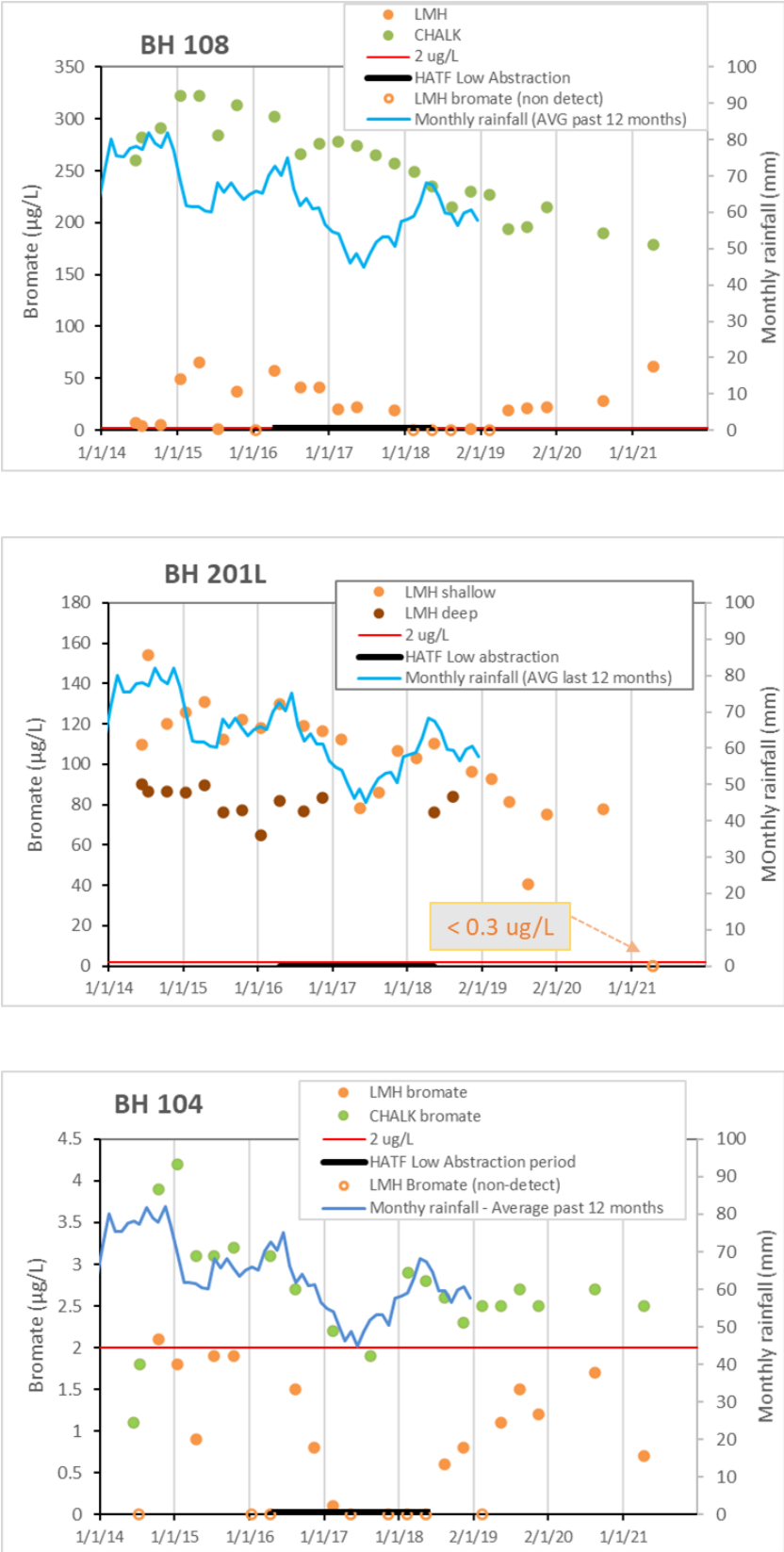


Fig. 2. Bromate concentrations at monitoring points BH108, BH201L and BH104 located increasingly close to the quarry Site.

- **BH201L** - Comparison is of shallower and deeper points in the LMH. The borehole is very close to the Site perimeter and shows much higher concentrations around 100 µg/L bromate than BH108 (see above) laterally closer to the plume core. Hence this discrepancy shows heterogeneity, discontinuous variability of the plume edge and requirements for high spatial resolution to reliably contour that plume edge. Bromate in the shallow LMH is consistently higher and more variable than the bromate in the deeper LMH – showing the importance of increased shallow contamination in the LMH. Together they suggest high bromate concentrations occur over the LMH thickness to around 50 times the 2 µg/L plume threshold very close to site. Such contamination may likely be drawn in to Site by any quarry abstraction from the LMH. Deeper LMH shows quite constant bromate and contrasts with the shallow LMH bromate that exhibits declining bromate with time. The shallow LMH appears to show correlation with rainfall, but with increased bromate often observed with increased rainfall – this is the opposite relationship to rainfall indicated in the SoCG. This correlation may suggest increased leaching of shallow source area bromate up gradient by higher groundwater levels in response to increased rainfall that is captured by this scale of shallow monitoring. It shows the importance of near site LMH gravels receiving shallow contamination from the Chalk up gradient that results in bromate concentrations extremely close to the quarry site at very high concentrations. Relationships to the reduced Bishop's Rise abstraction period are not obvious. SLR flagged the significance of recent low concentrations detected near Site (in Conditions discussion) exemplifying 201. However, this refers to a single isolated sample in 2021 below detection limit (Fig. 2) that on first inspection would appear very anomalous. It would certainly require confirmatory sampling, especially given the lower sampling frequency of late. Little weight could be given to that sample at present without further sampling.
- **BH104** - boreholes are located at the Site NE corner perimeter and show Chalk bromate at 2 – 4 µg/L just above a 2 µg/L plume threshold and LMH bromate usually below, but approaching the 2 µg/L threshold. Trends again are notably different in LMH and chalk and do not suggest local hydraulic continuity between them and somewhat separate plume migrations in the chalk and LMH at the plume margins (which would be reasonable to expect hydrogeologically). A relationship to rainfall is not obvious for LMH but is for the chalk. Again, this is the opposite correlation observed at this local scale to that indicated more generally in the SoCG. Again, higher rainfall and higher water levels exhibiting higher bromate suggesting again the importance of leaching shallow source zones of bromate at high water table. A relationship of the 104 LMH bromate to the HATF (Bishop's Rise) low abstraction 2016-18 period, although questioned by AW, does appear a valid interpretation to consider. Similar to 108, bromate appears to gradually decline during the abstraction low followed by a gradual increase over 2 to 3 years back to the pre-low-abstraction period concentrations as abstraction increases. This may be reasonably interpreted as a slow lateral drift of the plume transversely across 104 in the LMH back and forth away from

and then towards the Site (recognising other processes may co-influence concentrations). If correct, then linking of increased Site bromate with increased and sustained Bishop's Rise abstraction rates has important Site implications, i.e. sustained pumping at even higher pumping rates may draw yet higher bromate concentrations into the Site. I do concede that some of the LMH bromate non-detects do not fit my interpretation, but would be interested to establish actual pumping conditions at actual sampling. Continued 104 monitoring with Bishop's Rise pumping at 5 Ml/d would be illuminating – if concentrations maintain around 2 µg/L without low concentrations this would add weight to my argument. If frequent low concentrations occur then other controlling processes are (also) significant.

It is clear that bromate plume behaviours may potentially contradict at the local monitoring point scale some of the plume conceptualisation statements in the SoCG. These are exemplified in Figure 3, a page copied from my ID-15 submission. It is important to resolve the controls as far as possible to predict risks of bromate plume entry or occurrence on site and appropriate design of monitoring points and measurement frequencies to prove absence or presence of bromate on Site. My main key difference with respect to the SoCG opinion would be the potential influence of Bishop's Rise abstraction rates on near site boreholes such as BH104. And also, the extended timeframes (of up to a year or two) for bromate concentrations in the LMH to respond to significant, prolonged changes in abstraction rates.

Statement of Common Ground text

- 4.3

Despite the fact that in the main part of the plume (to the north of the proposed quarry) the LMA can also have bromate-rich water, the primary mechanism for bromate scavenging at HATF is through the Chalk with minimal downward leakage through the LMA [aka LMH].

- In fact, since 2018 when the HATF abstraction became more stable at c4.5Ml/d, the bromate ratio between LMA and Chalk has stabilised, indicating that a steady state condition has been reached with fixed leakage between LMA and Chalk.
- The bromate concentration at both the LMA and the Chalk is primarily influenced by rainfall/recharge resulting in greater dilution during wet years and less during dry years.
- HATF abstraction is considered to be a secondary influence on the bromate plume at the proposed quarry, as demonstrated by the water quality data collected since 2018 (with stable abstraction).

Some of my responses:

- BUT, this still does NOT negate the fact that all bromate in the Site LMH and in the LMH to the immediate north of the Site falling in the shown capture zone in the LMH (water table maps) will be draining into the Chalk and be scavenged.
- The percentage split of bromate mass scavenged by HATF between (i) that has passed through the chalk-LMH-chalk pathway versus (ii) chalk only, has not been estimated (and would be subject to quite a lot of uncertainty) and needs to be estimated to fundamentally support this statement.
- My analysis of data further below does not fully support this stabilisation has occurred – the ratios are still quite variable in time and between points. My impression is that the time (2-3 years) for stabilisation of the bromate plume in the LMH gravels in response to the changes in abstraction rate before and after 2018 is NOT appreciated (see later) and is critically important.
- My analysis of data further below provides a fair number of instances where this primary influence is NOT followed and the reverse is true. The LMA and Chalk can show quite different behaviours and each requires consideration.
- I also contest this, my analysis below suggest that for some wells in the LMH in or close to site (eg. 104, 108) that the HATF abstraction rates are the primary control on bromate occurrence
- Given these and other concerns, I do hold reservations that bromate plume behaviour in the LMH (LMA) is inadequately conceptualised.

Figure 3. Image of Page 3 of my submission ID-15 indicating some of my differences in opinion with some of the SoCG statements conceptualising the bromate plume problem and Site interaction.

[3] Questioning plume stability local to the Site?

I questioned in ID-15 the SoCG claimed stability of the plume, for instance the bromate concentration ratios between the LMH and chalk are quite variable (page 14 of ID-15). Included within ID-15 (but failed to raise in the Appeal) is a plot of bromate concentrations in borehole 061 (Hatfield quarry) located to the immediate north-east of the proposed quarry Site that is shown alongside bromate plume figures shown for 2014 and 2019 in Figure 4. Bromate shows very high concentrations local to the Site that exhibit an unusual U-shaped profile with concentrations very steadily rising over the decade since the 2010 low point and now reaching around 100 µg/L with some plume lateral expansion towards site evident when comparing the 2014 and 2019 plumes. Given concentrations approached 250 µg/L historically, and the plume flowlines from this point skirt along the edge of the quarry development it is important to understand the controls on the bromate concentrations observed at this monitoring point. My guess is that these gradual trends in bromate with time are abstraction variation related(?). Understanding this concentration profile with time appears critical to understanding the temporal trends in bromate in the immediate site vicinity and possible bromate plume entry into the Site area.

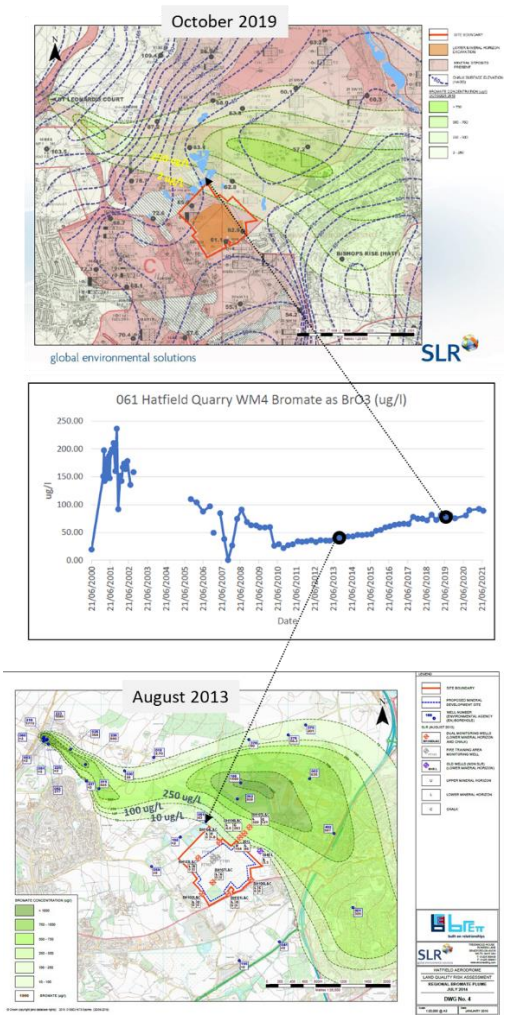


Fig. 4. Borehole 061 bromate concentrations with time shown in relation to 2014 and 2019 bromate plume maps taken from SLR reporting.

[4] Concern: bromate may further enter the Site LMH if Bishop's Rise is pumped at 9 Ml/d licensed rates that should remain as a scavenging option and not jeopardised by quarry development

AW indicated at the Appeal that the ideal would be to operate Bishop's Rise at its full licensed rate of 9 Ml/d to provide the maximum scavenging of the bromate plume and maximum protection of ESSE and other abstractions further down gradient. Given the choice, would most residents vote for operation at 5 Ml/d (the current typical operational rate) or 9 Ml/d? Whilst I recognise the reasons for typical operation at 5 Ml/d (see Rowland PoE for instance), in my opinion operation at the licensed 9 Ml/d should at minimum remain an available scavenging option. My major concern is that a permitted quarry Site would jeopardise or reduce the efficiency of that operation in that operation at 9 Ml/d may well draw part of the bromate plume through the Quarry site that would later be compromised by the low permeability backfill of the Site. Indeed, the SoCG seems at pains to confirm that previous operation of Bishop's Rise (HATF) at around 9 Ml/d has not resulted in bromate contamination on Site with the implication being that the signatories too also value this scavenging capacity.

The SoCG indicates "*Under low pumping at HATF the southern boundary of the plume moves north, while higher pumping rates cause this boundary to move south. However, even under scenarios where HATF has pumped at or near its maximum licensed volume (9Ml/d, in the past between 1995 and 2000 and more recently in 2013/14 and 2018), the southern plume boundary has been shown not to move onto the proposed quarry site.*". As set out in my document ID-15 (page 17), and following discussions at the Appeal and a brief excursion into the topic at the setting of groundwater conditions discussion, I would dispute all of the evidence provided in support of this for the following reasons:

- Regarding pumping at (or near) 9 Ml/d in 2013/14 and 2018 (both at 7 Ml/d), I maintain based on the slow around 2 years rise in concentrations post the 2016-18 reduced pumping period in BH104 (and BH108) (Figure 2) that Bishop's Rise has not been pumped at a high abstraction rate for nowhere near long enough to achieve a bromate plume steady state in the LMH in order to establish the degree to which the bromate plume may move on to Site induced by the higher Bishop's Rise abstraction rate.
    - In 2018, whist adequate site monitoring wells were available the 7 Ml/d period was for only a few weeks and too soon after the 2016-18 low pumping period
    - In 2013-14, although a longer period of 7 Ml/d of around 4 months this is still too short in my opinion and in any case the bromate detection limit was too high at 100 µg/L and very unlikely to observe contamination at probable concentrations expected based on the near Site data now available.
- 1995-2000: I am unclear what the evidence of referred to in the SoCG above of what evidence there is of the pumping at 9 Ml/d between 1995 – 2000 not resulting in bromate on Site. Is there any on Site or near Quarry Site monitoring actually available to cover that period? I stand to be corrected, but it appears that the evidence being offered to cover the 1995-2000 period is the EA's indication that they do not see evidence of a diffusional past footprint in the recent site monitoring? If that is the

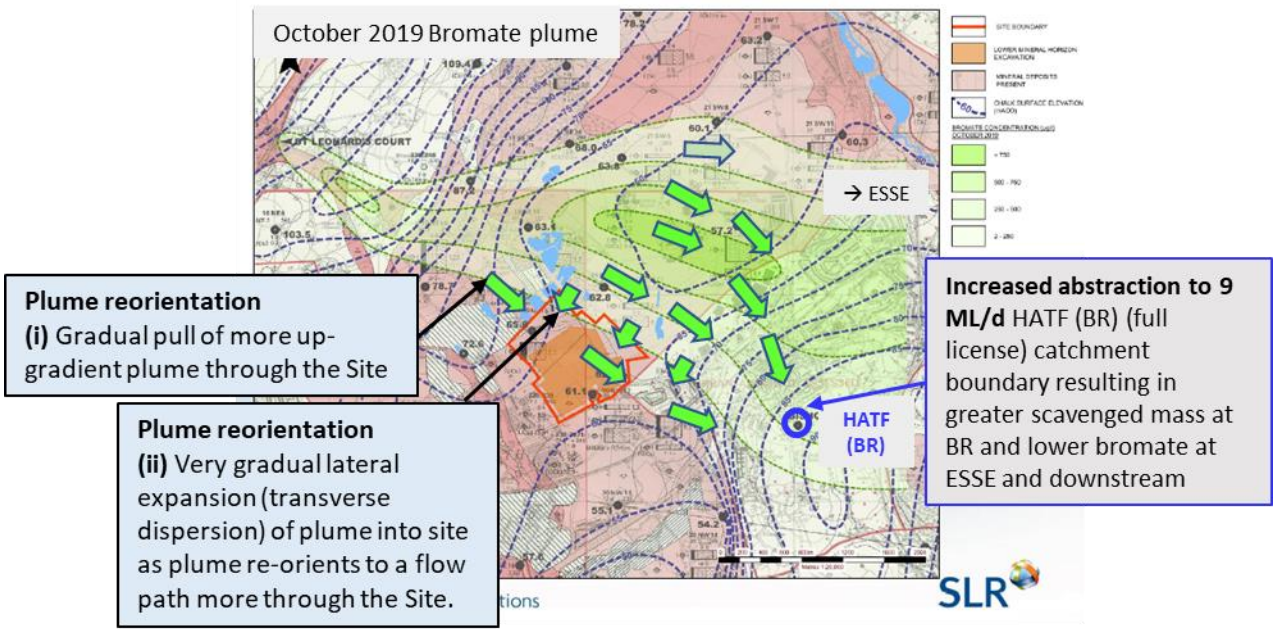
evidence, I would refute it. Any diffusional footprint in the low to modest concentration plume periphery will be very weak and very likely below detection limits. It will likely be weaker in the LMH than the chalk. It would likely require high resolution multilevel 'point' groundwater sampling (rather than conventional borehole or monitoring well screens used) to stand any chance of resolving a diffusional footprint in the plume periphery and targeted sampling of the silts/clay horizons that yield little water and are easily diluted. Also, any detections made (e.g. the sporadic detections made on site at low level) would be impossible/difficult to attribute to old plume passage and not recent plume passage.

- The signatories are requested to clarify their evidence for the 1995-2000 statement in particular, and also the 2013-14 period.

Conceptual model of the issue – In my opinion the evaluation of increased Bishop's Rise abstraction rates should consider more carefully that the bromate plume may be displaced slowly sideways with increased Bishop's Rise abstraction rates, moving south and perpendicular to its main flow direction. The banana-shaped plume is being slightly straightened on its inside bend, towards Site, causing a gradual lateral drift into the site at the north east (borehole 104) boundary. Fig. 5 shows a conceptual model of the possible influence of increased abstraction at Bishop's Rise from the typical 5 Ml/d to 9 Ml/d (licensed rate) potentially causing slow plume reorientation through part of the quarry Site. Two components of plume reorientation are depicted: (i) a Gradual pull of the more up-gradient plume through the Site; and, (ii) Very gradual lateral sideways expansion (transverse dispersion) of plume into site as plume re-orients to a flow path more through the Site. On (ii), the sideways motion of a plume is difficult as, technically, transverse horizontal dispersion (sideways spreading) of plumes is a weak process. It will be more difficult to re-align the bromate plume sideways in the LMH gravels than the chalk as the hydraulic gradients are less (as more removed from the chalk adits influence, gravels have higher (mobile porosity) storage than the chalk). Within the LMH itself, plume sideways motion will be more difficult in the lower permeability sands than in the gravels and may be one reason why LMH boreholes are showing different responses to Bishop's Rise pumping (Figures 1 and 2). The predominant orientation of individual beds ('lenses') of gravel, sand and silt sub-deposits will be significant. If elongated bed directions are aligned with flow directions encouraging flows along them, or if perpendicular inhibiting flows and lengthening timeframes.

In the absence of convincing evidences, the 'acid-test' would be for Bishop's Rise to be pumped at 7-9 Ml/d continually for at least a year, ideally 2 years or more, continuing quarterly (at minimum) baseline sampling of monitoring wells. This would be the only reliable way in my opinion of safeguarding the option to operate the Bishop's Rise scavenger well at its full 9 Ml/d rate and verify if the bromate plume does, or does not migrate on to the Site at those rates. If the plume is shown to migrate on to Site at those abstraction rates then the proposed quarrying would jeopardise scavenging system capability due to the installation of backfill that would interfere with that subsequent remediation performance and scavenge of LMH bromate. Also, for the quarrying then to be viable, it would rely on the discretion of AW not to operate Bishop's Rise at high 7 – 9 Ml/d rates that may cause bromate plume invasion to parts of the Site. Prior to such a high-rate abstraction test, continued Site quarterly

monitoring with Bishop's Rise abstraction consistently continuing at 5 Ml/d is essential to fully confirm bromate current plume – Site interaction behaviour at those abstraction rates for a prolonged period.



Plume basemap from Slide 4 of SLR's Hatfield Aerodrome Mineral Development Site SoCG Questions and Clarifications

Fig. 5. Conceptual model of increased abstraction at Bishop's Rise from typical 5 Ml/d to 9 Ml/d (licensed rate) potentially causing slow plume reorientation through part of the quarry Site (note the flow diversions are illustrative of the concept, not actual or modelled).

[5] Stand-off distance and plume boundary definition concerns

I have previously raised the concern of a 'half-a-mile gap' in the critical north-east Site boundary monitoring of the LMH (ID-15, page 4). This remains a concern. The appellant proposes in the Appeal a 100-m standoff from the plume pointing to BH104 as a key defining point where, per above, plume concentrations in the LMH are shown to approach 2 ug/. My initial, now I find mistaken impression, was that the same would apply elsewhere along the north-east side of the Site to allow a similar 100 m stand-off from the plume (2µg/L) edge. It seems though this could sensibly and reasonable apply as a conservative measure. The clear down-side in the half-a-mile gap in the monitoring means that the plume edge is not well defined and hence the stand-off distances from the plume of the development also not possible to define with confidence. Whilst I recognise the proposal is to add a couple of monitoring wells to fill in the gap, I still question if this will be sufficient to confidently delineate a plume 2 µg/L plume boundary to then set a reliable stand-off distance 100 m back from that defined plume boundary. I would advocate that site investigation more monitoring wells is required for the reasons below:

- The present plume contouring is largely and likely exclusively based on the monitoring of the chalk bromate and not the LMH gravels (I stand to be corrected)

- To be conservative, the standoff distance should consider bromate in both the chalk and LMH
- The plume edge boundary is likely to be quite different in the chalk and the LMH as suggested by the Figure 2 data. Whist it could be argued that the chalk bromate is higher than LMH and the plume boundary could be defined from the chalk data, it would be cautious to presume that this is not always going to be the case – bromate concentrations per above may lag those in the chalk as it is more 'sluggish' to respond to plume migration.
- The ~2 µg/L plume boundary is unlikely to be smooth, but 'ragged' – for instance where the bromate plume has 'drifted' or dispersed towards the Site, it is very likely to have migrated closer to Site in the more permeable gravel lenses and less close in the permeable silts and finer sands. The variation in permeability of sub-deposits within the LMH will control the plume edge migration proximity to Site and the expected predominant orientation of the gravel beds in the paleochannel in this area (this should be clarified by the appellant).
- Whilst definition of every wiggle and bump in the plume edge would be clearly unreasonable, the proposed number of wells appear insufficient for reasonably confident definition of a plume boundary and assured 100 m stand-off.
- A consideration that is the proposed monitoring wells do show a bromate detection significantly above 2 µg/L, then further wells would be required further inward to the Site – a second transect of monitoring wells? It may be prudent to install a larger number of wells for bromate investigation purposes, but ultimately only retain a couple, as proposed, selected for longer term monitoring?
- There should be some confidence that the LMH lagoon, proposed, for this area is not in the plume.
- My recommendation would be that a site investigation using about 10 boreholes (two transects of 5 wells set parallel to the perceive plume edge) is used along the northeast boundary of Site to delineate the approximate plume 2 µg/L boundary and hence where Site ground invasive operations can be located with confidence around 100 m from the plume. The boreholes should be monitored for a year (with Bishop's Rise operating consistently at 5 Ml/d) with a view to 2 of these boreholes being retained for long term monitoring.

[6] Quarry site abstraction – draws down the high K routes where the plume is likely most advanced

I only comment lightly on Quarry Site abstraction influence in view of the new proposals for no abstraction at all in any Phases. I would have high concerns from examination of the Figure 2 data that bromate contamination at significant concentrations is very close to the Site in the LMH and chalk and would be drawn into Site as outlined in my previous submission and supported by the Lightfoot Proof of Evidence. I additionally emphasise the following if pumping was to occur:

- The heterogeneity in the LMH needs to be recognised and in particular that the bromate plume is likely to have migrated closest to site in the more permeable gravel beds within the LMH deposits. These same gravel deposits will of course be the deposits from which groundwater would be primarily abstracted. The clear concern is that the abstraction will greatly accelerate the velocities of plumes within the gravels compared to the less permeable deposits. Essentially the plume will 'finger' its way towards the abstraction in these permeable gravel beds. The slow sideways drift of the plume in the gravels potentially induced by the Bishop's Rise abstraction in the chalk conceptualised in Figure 5, would no longer apply – this would be vastly overshadowed by the local Quarry abstraction from the LMH that would result in accelerated migration of the bromate towards Site.
- Per earlier, there needs to be clear statements on the expected orientation in the LMH paleochannel of the individual deposits, gravel beds etc, occurring between the Site and the main plume – are these oriented perpendicular to the plume boundary and effectively function as a 'pipeline' into the Site when abstraction occurs, or are they oriented more parallel to the plume boundary enabling the lower permeability units to serve as a partial barrier to a degree? The former case would be clearly of more concern in enhancing bromate migration rates towards Site when pumping occurs. The latter case would allow a slower migration towards Site of bromate, but also inhibit its release away from Site once pumping is terminated. This control needs to be clarified as far as possible.

[7] Low permeability backfill diversion of plume component northwards beyond reach of Bishop's Rise

I have raised the low permeability backfill diversion of plume component primarily northwards beyond reach of Bishop's Rise in ID-15. I agree though with the concern raised in the Appeal that Page 20 schematic (b) of the near Bishop's Rise flow lines - capture zone was poorly conceptualised by myself, but not fully with the point raised (as I understood it – I stand to be corrected) that Bishop's Rise would full capture bromate in the LMG gravels. I provide two figures below that correct the schematic conceptualisation and address these points. I maintain this is an influence to be considered.

Figure 6a shows the source protection zone (SPZ) base map annotated with approximate flow divides between groundwater flowing to Bishop's Rise (HATF) versus ESSE (Essendon) for: licensed (9 ML/d) and more typical 5 Ml/d abstraction rates for Bishop's Rise. The lines are approximate, especially the later which presumes ESSE is maintained at it licensed abstraction rate. The main point on the 5 Ml/d flow divide line is that the capture zone of Bishop's Rise will be somewhat reduced, less extensive from the abstraction. Fig. 6b plots the approximate flow divides shown on a base map of glaciofluvial sands and gravels (i.e. U/LMH) and bromate plume. Based on this conceptualisation, some of the bromate plume in the gravels (the plume presumed to lie approximately above the shown chalk plume where the gravels are present) will be drawn towards Bishop's Rise and some towards ESSE (and possibly down gradient

captured by neither abstraction). A lower proportion would be captured by Bishop's Rise pumping at its typical 5 Ml/d than would be at its full licensed rate.

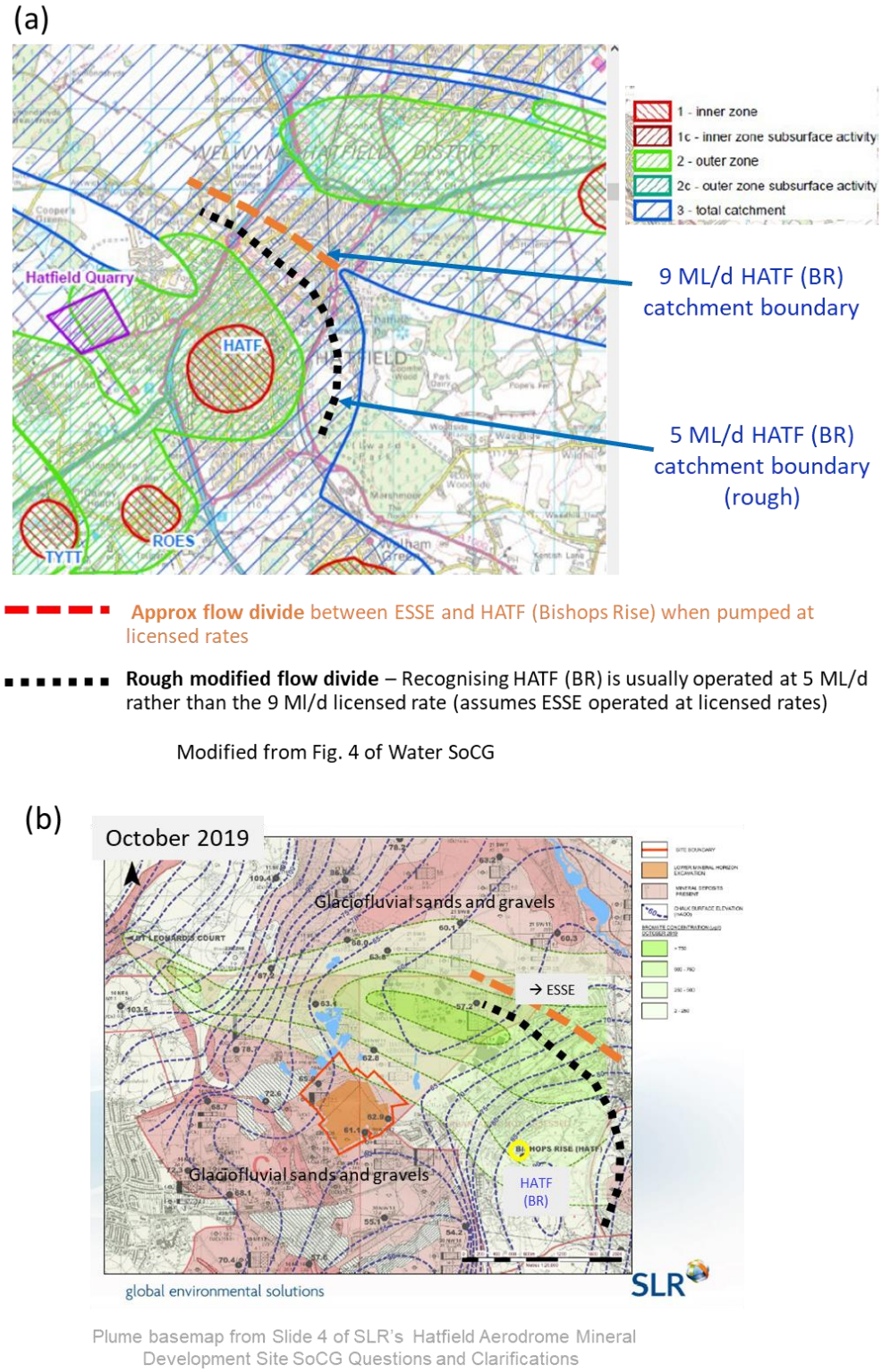
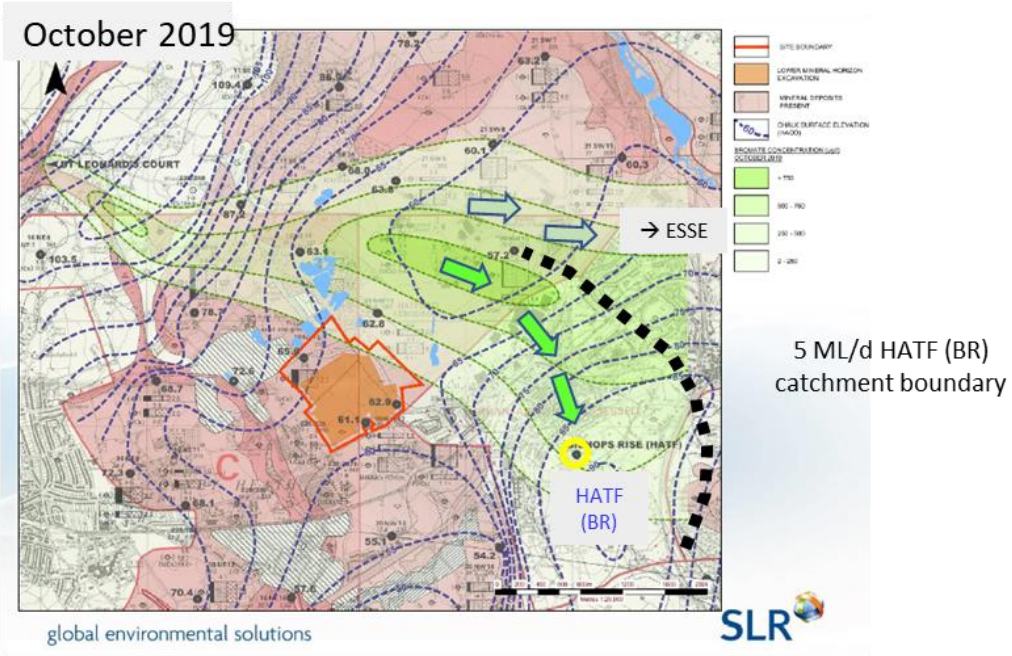


Fig. 6. (a) Source protection zones base map annotated with approximate flow divides between groundwater flowing to Bishop's Rise (HATF) versus ESSE for licensed (9 ML/d) and more typical 5 Ml/d abstraction rates for Bishop's Rise; (b) approximate flow divides shown on a base map of glaciofluvial sands and gravels (U/LMH) and bromate plume.

Figure 7 extends Figure 6b with the addition of arrows conceptualising the bromate plume split. Figure 7a depicts existing flow conditions and approximate catchment for 5 Ml/d abstraction at Bishop's Rise and Figure 7b showing schematic illustration of displaced plume bromate arising from groundwater flow diversion in the LMH around the low permeability backfill. The profile in the plume core, the bend southwards, would support that the shown capture zone split is likely in the right region, at least approximately.

(a)



(b)

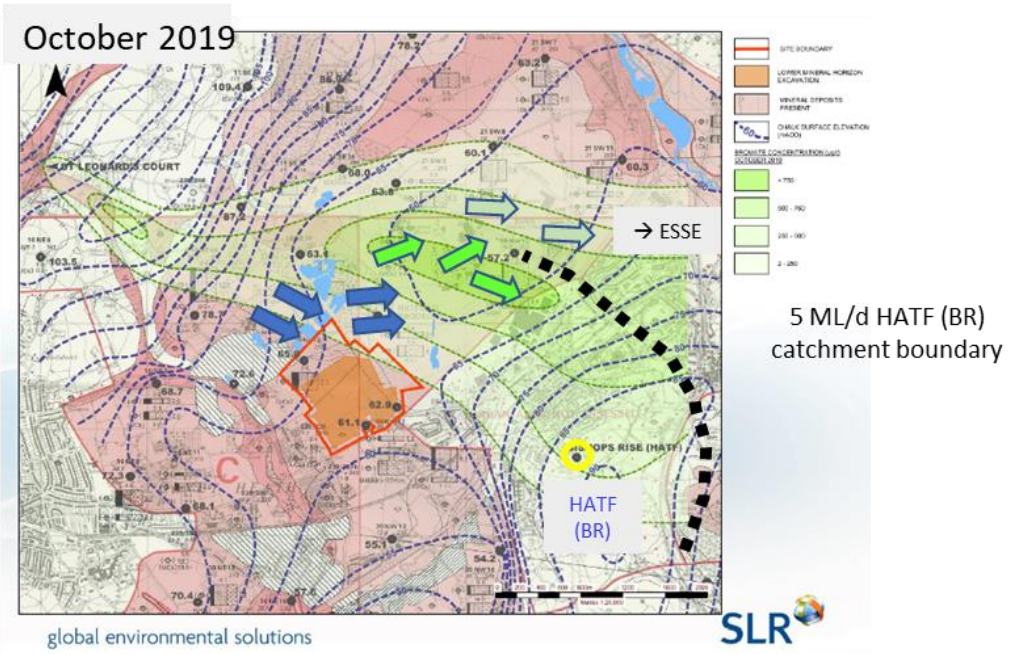


Fig. 7. As per Figure 6b, with addition of arrows conceptualising the bromate plume split under (a) existing flow conditions and approximate catchment for 5 Ml/d abstraction at Bishop's Rise and (b) schematic illustration of displaced plume bromate arising from groundwater flow diversion in the LMH around the low permeability backfill.

Some summary points may be briefly made:

- Groundwater flow calculations if done using the transmissivity values and gradients in the SLR reporting for the LMH would indicate a significant volume of groundwater flow will be diverted around the low permeability backfill.
- The split between flow underneath and around is unknown, noting that local hydraulic continuity with the chalk cannot be presumed for flow underneath and may locally vary with connectivity to the more horizontal chalk fractures transmitting flow.
- Current hydraulic gradients suggest most flow diversion would occur northwards towards the main bromate plume and will inevitably lead to some displacing – shunting of the bromate plume northwards by likely cleaner groundwater diverted around the backfill.
- Monitored bromate concentrations on or near the site perimeter will likely reduce.
- The 5 Ml/d capture zone shown in Figure 7b is likely very close to the high bromate concentration plume core and hence capture of these high concentrations. Hence, if the shunt in groundwater and plume northwards, if conveyed that far north, may lead to high concertation portions of the plume near the core evading capture by Bishop's Rise.
- A key question is then will the groundwater displacement effect be sufficient to reach and displace concentrations beyond the capture zone reach. I agree it is a long way, but again the flow diversion is potentially quite large and will be influenced by the direction of the bedding of the gravels, which if aligning with the paleo-channel direction that could be assumed as a first approximation (Fig 7 basemap contours trending from South-west to North-east), would align favourably to push the plume north-eastwards as shown. The influence would be best numerically modelled to establish its preliminary significance or not.